

Comment on the paper “Dark matter searches going bananas: the contribution of Potassium (and Chlorine) to the 3.5 keV line” by T. Jeltema and S. Profumo

A. Boyarsky¹, J. Franse^{1,2}, D. Iakubovskiy³, and O. Ruchayskiy⁴

¹Instituut-Lorentz for Theoretical Physics, Universiteit Leiden, Niels Bohrweg 2, Leiden, The Netherlands

²Leiden Observatory, Leiden University, Niels Bohrweg 2, Leiden, The Netherlands

³Bogolyubov Institute of Theoretical Physics, Metrologichna Str. 14-b, 03680, Kyiv, Ukraine

⁴Ecole Polytechnique Fédérale de Lausanne, FSB/ITP/LPPC, BSP, CH-1015, Lausanne, Switzerland

(■Dated: August 20, 2014)

We revisit the X-ray spectrum of the central 14' of the Andromeda galaxy, discussed in our previous work [1]. Recently in [2] it was claimed that if one limits the analysis of the data to the interval 3–4 keV, the significance of the detection of the line at 3.53 keV drops below 2σ . In this note we show that such a restriction is not justified, as the continuum is well-modeled as a power law up to 8 keV, and parameters of the background model are well constrained over this larger interval of energies. This allows for a detection of the line at 3.53 keV with a statistical significance greater than $\sim 3\sigma$ and for the identification of several known atomic lines in the energy range 3–4 keV. Limiting the analysis to the 3–4 keV interval results in increased uncertainty, thus decreasing the significance of the detection. We also argue that, with the M31 data included, a consistent interpretation of the 3.53 keV line as an atomic line of K XVIII in all studied objects is problematic.

Earlier this year, two independent groups [1, 3] reported a detection of an unidentified X-ray line at an energy of ~ 3.53 keV in the long-exposure X-ray observations of a number of dark matter-dominated objects. The possibility that this spectral feature may be the signal from decaying dark matter has sparked a lot of interest in the community as the signal has passed a number of “sanity checks” expected for a dark matter decay signal: it scales correctly between galaxy clusters, the Andromeda galaxy, the Milky Way center and the upper bound from non-detection in the blank sky data [1, 4], and also between different subsamples of clusters [3]. The signal has radial surface brightness profiles in the Perseus cluster, Andromeda galaxy [1] and in the Milky Way [4] that are consistent with our expectations about the dark matter distribution in these objects.

Recently, the authors of [2] have argued that if one restricts the modeling of the emission of the central part of M31 to the energy range 3–4 keV, and uses a single powerlaw as a model of the continuum, the significance of the detection of the line at 3.53 keV in the spectrum of M31 drops below 2σ . They also argued that when one ignores the detection in M31, the line in the spectra of the galaxy clusters and of the Galactic Center can be explained by an atomic transition in the K XVIII ion, provided one also assumes both an abundance of K XVIII and a set of physical conditions in these objects that are hard to exclude.

In this note we show that restricting the analysis of the M31 spectrum to 3–4 keV is not justified. The continuum is well modelled by a power law model up to 8 keV and the parameters of this model are well constrained at this wider interval. Limiting the analysis to 3–4 keV only results in increased uncertainty and, although the flux in the 3.53 keV line is consistent with the one reported in [1], the significance of its

detection is naturally smaller on the 3–4 keV than on the whole 2–8 keV interval, where the astrophysical background is better constrained. We also argue that with the M31 data included, the interpretation of the 3.53 keV line as a K XVIII line in several studied objects together is problematic.

We start by repeating the analysis of [2]: we fit the M31 spectrum over the interval 3–4 keV with a single powerlaw (in order to avoid having to model the instrumental background, we subtract it from our spectra.)¹ The fit is good ($\chi^2 = 22.4$ for 27 d.o.f.).² The parameters of the powerlaw are: PL index 1.65 ± 0.05 (3% relative error), and PL norm $(1.19 \pm 0.07) \times 10^{-3}$ cts/sec/cm²/keV at 3.5 keV (the relative error being 6.3%). An additional line is detected against this continuum at energy 3.53 keV and with normalization $(2.7 \pm 1.5) \times 10^{-6}$ cts/sec/cm² (less than 2σ significance, $\Delta\chi^2 = 3.4$ when adding this line). Thus, we have reproduced both the flux and the significance reported in [2].

However, once we extend the powerlaw obtained over the interval 3–4 keV to higher energies, we see that it *significantly overpredicts* the count rate in all energy bins above 4 keV as Fig. 1 demonstrates.

Let us now compare this result with the fit over the whole interval 2–8 keV (as in Ref. [1]). The wider range of energies allows us to determine the parameters of the powerlaw

¹ The spectral modeling has been performed with the X-Ray Spectral Fitting Package `Xspec` [5] v.12.8.0.

² Unlike [2] we have binned the spectrum by 60 eV (as in [1]) to make bins roughly statistically independent. We verified that our conclusion does not change for finer binning.

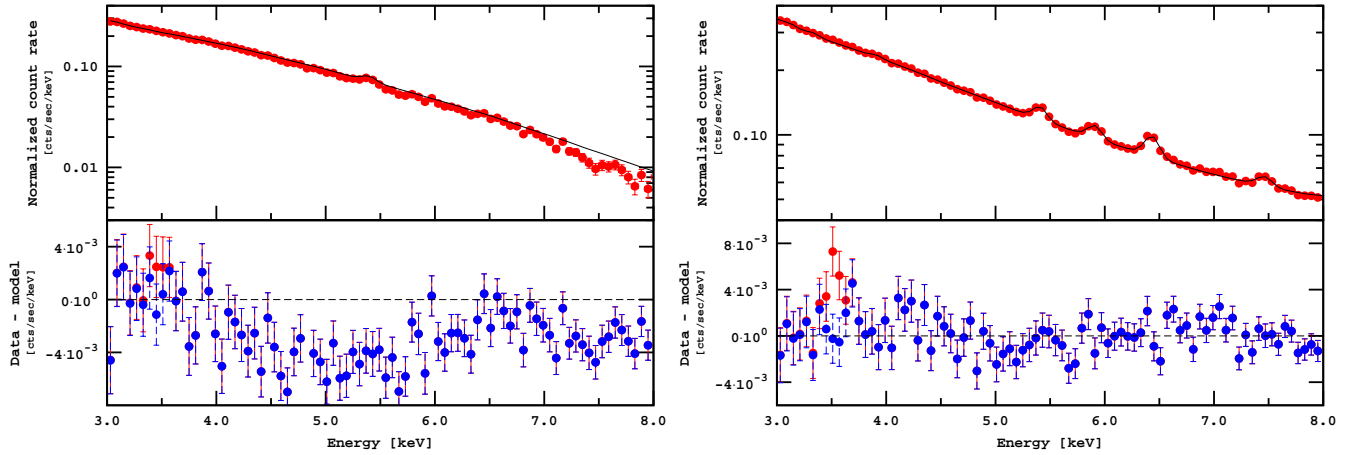


FIG. 1: *Left panel*: Best fit powerlaw, as determined over the 3–4 keV interval in [2], extended to higher energies. Such a powerlaw significantly overpredicts the count rate in all bins at $E > 4$ keV. A wide group of near-zero residuals around 6.5 keV corresponds to the complex of lines of iron and other elements (unmodeled). *Right panel*: The data over a wider range of energies processed and fitted in [1]) with the line at 3.53 keV unmodeled. Other lines in the range 3 – 4 keV are included in the model.

with better precision: PL index 1.71 ± 0.01 (0.5% relative error), PL norm = $(1.18 \pm 0.01) \times 10^{-3}$ cts/sec/cm²/keV at 3.5 keV (0.7% relative error). The improvement of the quality of fit when adding the line around 3.53 keV was $\Delta\chi^2 = 13$ (which is about 3σ for 2 degrees of freedom: position and normalization of the line). This is the most significant feature in the 3–4 keV range. In Table I we list all the lines detected in the interval 3–4 keV with significance more than 1σ . Unlike the results of [2] (see Fig. 3 therein), the lines at 3.91 keV (complex of CA XIX and AR XVII lines) have also been detected in this case with the significance above 2σ . In the case of the fit over the 3 – 4 keV range, these lines were partially compensated by the powerlaw continuum. In addition, the parameters of the continuum as determined over the narrow range of energies naturally suffer from larger errors (around 3 – 6% for the fit over 3 – 4 keV interval vs. 0.5 – 0.7% for the fit of [1]). As the flux in the line in question is about 4% of the continuum at these energies, the parameters of the background model should be determined with a precision greater than that in order to reliably detect such a weak line. This explains the reduced best-fit flux and the diminished significance of the line at 3.53 keV.

Finally, we make the observation that complexes of argon, cal-

cium and sulphur at energies 3.14 keV, 3.37 keV and 3.91 keV (of which only the 3.91 keV complex is detected at more than 2σ) have fluxes *lower* than that of the unidentified spectral feature at 3.53 keV. This *challenges* the interpretation of the feature as a K XVIII complex. Indeed, according to AtomDB v2.0.2 [6] K XVIII emissivity is at least an order of magnitude lower than emissivities of the complexes in the intervals 3.85 – 3.95 keV and 3.08 – 3.18 keV (see Fig. 2 based on the data from [6]). This relation between emissivities is based on the assumption of solar abundances for these elements. To change this conclusion a strongly super-solar abundance of K XVIII would be required.

In conclusion: the line 3.53 keV is detected at $\sim 3\sigma$ level in the spectrum of the Andromeda galaxy against a background model with the continuum component constrained at the 2–8 keV interval as in [1]. Fitting the data in the much narrower 3–4 keV range reduces the significance of the detection as the sensitivity likewise reduces with less data, however this does not contradict the flux in the line detected in [1]. The fit over the narrow interval of energies, as performed in [2], provides a best fit value of the slope of the power law background that systematically over-predicts the value of the flux above 4 keV, and is therefore significantly ruled out by the whole spectrum.

The observation of the line at 3.53 keV in the center of M31 is in stark contradiction with its interpretation as a K XVIII atomic transition – it would require an extremely super-solar abundance of K XVIII *and* a super-solar ratio of abundance of K XVIII relative to AR XVII and CA XIX. The presence of this line in different types of objects – galaxy clusters, M31, and the Galactic Center – makes it challenging to explain all these signals together by emission from K XVIII, even if this interpretation is hard to exclude from the GC data only.

Acknowledgments. We acknowledge useful discussions with

TABLE I: Position and flux of lines found in the central part of M31 [1], together with 1σ error ranges.

Line	Position, keV	Flux, ph/sec/cm ²
AR XVII/S XV	3.14 ± 0.04	$2.3 \pm 1.4 \times 10^{-6}$
AR XVIII/S XVI/CL XVI	3.37 ± 0.03	$3.6 \pm 1.4 \times 10^{-6}$
AR XVII/CA XIX	3.91 ± 0.02	$4.3 \pm 1.3 \times 10^{-6}$
DM line candidate	3.53 ± 0.03	$4.9^{+1.6}_{-1.3} \times 10^{-6}$

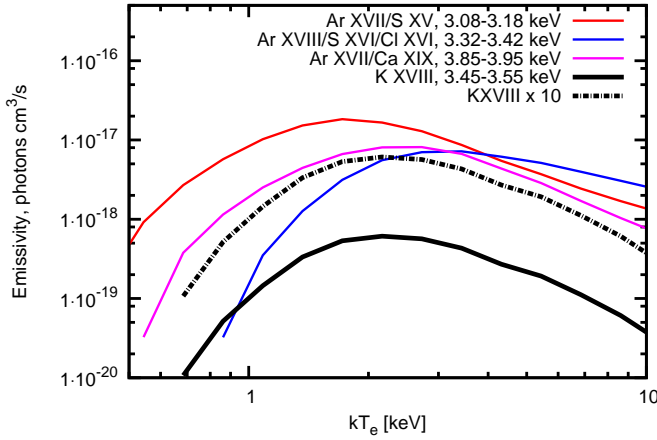


FIG. 2: Emissivities of different line complexes as a function of plasma temperature (assuming solar abundances of all elements). The emissivity of the K XVIII line complex near 3.5 keV is at least an order of magnitude below those of the other complexes. The data is from AtomDB v2.0.2 [6].

T. Jeltema and thank Mark Lovell for providing comments on the manuscript. The work of D. I. was supported in part by the Swiss National Science Foundation grant SCOPE IZ7370-152581, the Program of Cosmic Research of the National Academy of Sciences of Ukraine, the State Programme of Implementation of Grid Technology in Ukraine and the grant of President of Ukraine for young scientists. The work of J. F. was supported by the De Sitter program at Leiden University with funds from NWO. This research is part of the “Fundamentals of Science” program at Leiden University.

-
- [1] A. Boyarsky, O. Ruchayskiy, D. Iakubovskiy, and J. Franse, ArXiv e-prints (2014), 1402.4119.
 - [2] T. E. Jeltema and S. Profumo, ArXiv e-prints (2014), 1408.1699.
 - [3] E. Bulbul, M. Markevitch, A. Foster, R. K. Smith, M. Loewenstein, et al. (2014), 1402.2301.
 - [4] A. Boyarsky, J. Franse, D. Iakubovskiy, and O. Ruchayskiy, ArXiv e-prints (2014), 1408.2503.
 - [5] K. A. Arnaud, in *Astronomical Data Analysis Software and Systems V*, edited by G. H. Jacoby and J. Barnes (San Francisco, ASP, 1996), vol. 101 of *A.S.P. Conference Serie*, p. 17.
 - [6] A. R. Foster, L. Ji, R. K. Smith, and N. S. Brickhouse, *ApJ* **756**, 128 (2012), 1207.0576.